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Chapter

Application of Nanomaterials in Environmental Improvement

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Abstract

In recent years, researchers used many scientific studies to improve modern technologies in the field of reducing the phenomenon of pollution resulting from them. In this chapter, methods to prepare nanomaterials are described, and the main properties such as mechanical, electrical, and optical properties and their relations are determined. The investigation of nanomaterials needed high technologies that depend on a range of nanomaterials from 1 to 100 nm; these are scanning electron microscopy (SEM), transmission electron microscopy (TEM), and X-ray diffractions (XRD). The applications of nanomaterials in environmental improvement are different from one another depending on the type of devices used, for example, solar cells for producing clean energy, nanotechnologies in coatings for building exterior surfaces, and sonochemical decolorization of dyes by the effect of nanocomposite.

Keywords: nanomaterials, synthesis, solar cell, sonocatalyst, water purification

1. General introduction

The term nanotechnology is the creation of functional material devices and systems through the control of matter in the range of 1–100 nm and the ability to work at the molecular level, atom by atom to create large structures with fundamentally new molecular organization. Nanotechnology is the design, fabrication, and application of nanostructures or nanomaterials and the fundamental understanding of the relationships between physical properties, or phenomena, and material dimensions. It is a new field or a new scientific domain. Nanometer (nm) is one billionth of a meter (10^{-9} m). About 10 hydrogen or fife silicon atoms are arranged in a straight line approximately representing 1 nm in length, and these materials are characterized by at least one dimension in the nanometer range.

Nanomaterials are of interest because at this scale unique optical, magnetic, electrical, and other properties emerge. These emergent properties have great potential applications in electronics, medicine, and other fields. Nanomaterials are classified into nanostructured and nanophase/nanoparticle materials. The former refer to condensed bulk materials that are made of grains with grain sizes in the nanometer size range, while the latter are usually the dispersive nanoparticles [1]. According to this definition, a nanoparticle is considered to have zero dimensions (the dimensions' length is less than 100 nm). For example, wires, rods, and nanofibers are objects with one dimension, while thin films, plates, multilayers, and network nanostructures express two dimensions. And more clearly, a sphere or

cluster of nanophase materials of zero dimension is represented as a point-like particle that is determined by three dimensions of nanomaterials, as demonstrated in **Figure 1** [2]. There are several important applications of nanomaterials such as aviation and space, chemical industry, optics, solar hydrogen, fuel cell, batteries, sensors, power generation, aeronautic industry, building/construction industry, automotive engineering, consumer electronics, thermoelectric devices, pharmaceuticals, and cosmetic industry [3]. One of the most pressing challenges of our time is to find alternative energy sources which are environmentally friendly which is depending on used of nanomaterial's in different applications such as solar cell [4], paints [5] and other applications in the field of green chemistry [6].

2. Surface effects

Chemical and physical properties of a material, such as bulk or nanoscale, depend on its surface properties. But the volume of bulk materials remains unchanged when it is subdivided into an ensemble of individual nanomaterials, and the collective surface area is greatly increased [7]. **Figure 2** describes stages of surface to volume increase for bulk materials.

Melting temperature of nanomaterials depends on the number of surface atoms and the increases of surface to volume ratio (S/V) lead to decreases in particle size and melting point because of surface atoms that have a much greater effect on chemical and physical properties of nanoparticle [8]. The surface to volume ratio for a material or substance made of nanoparticles has a significant effect on the properties of the material, when materials made up of nanoparticles have a relative larger surface area and compared to the same volume of material made up of bigger particles. For example, the surface area of a sphere, $A = 4\pi r^2$, divided by its volume, $V = \frac{4}{3}\pi r^3$, produced a $3/r$ as ratio between them, or in terms of diameter d produced the ratio $(6/d)$. The ratio $(F = A/V)$ for large thin plates with thickness d is

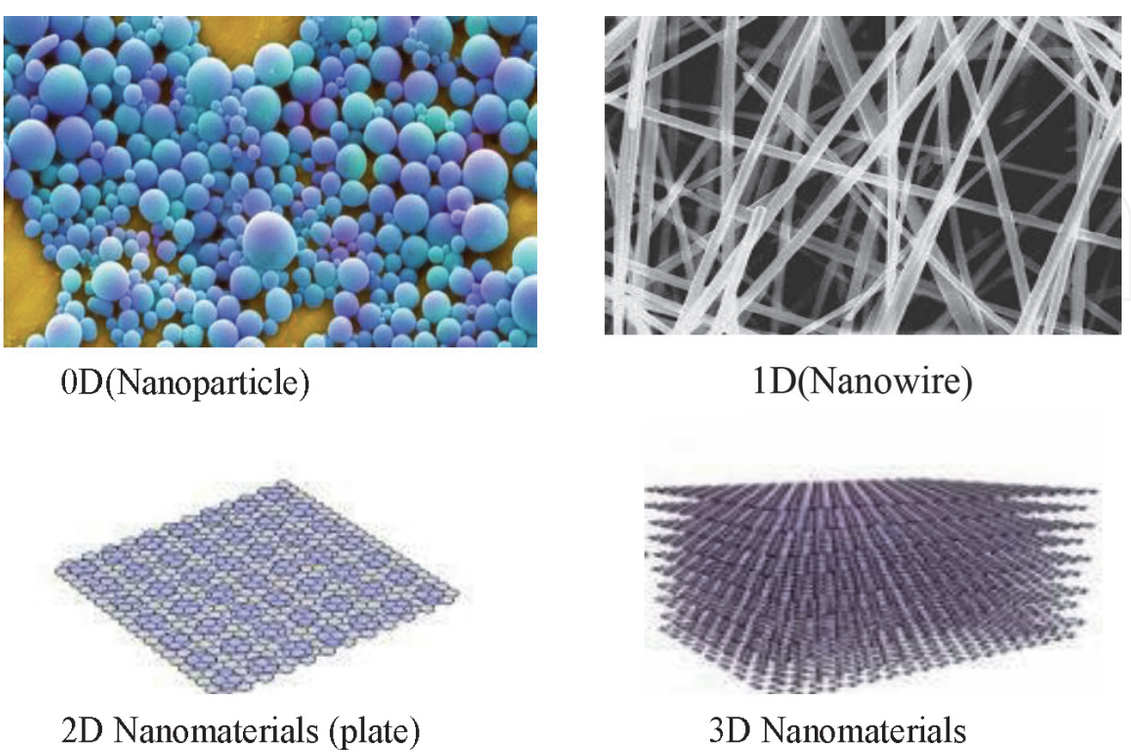

Figure 1.
Types of nanomaterials (0D, 1D, 2D, and 3D).

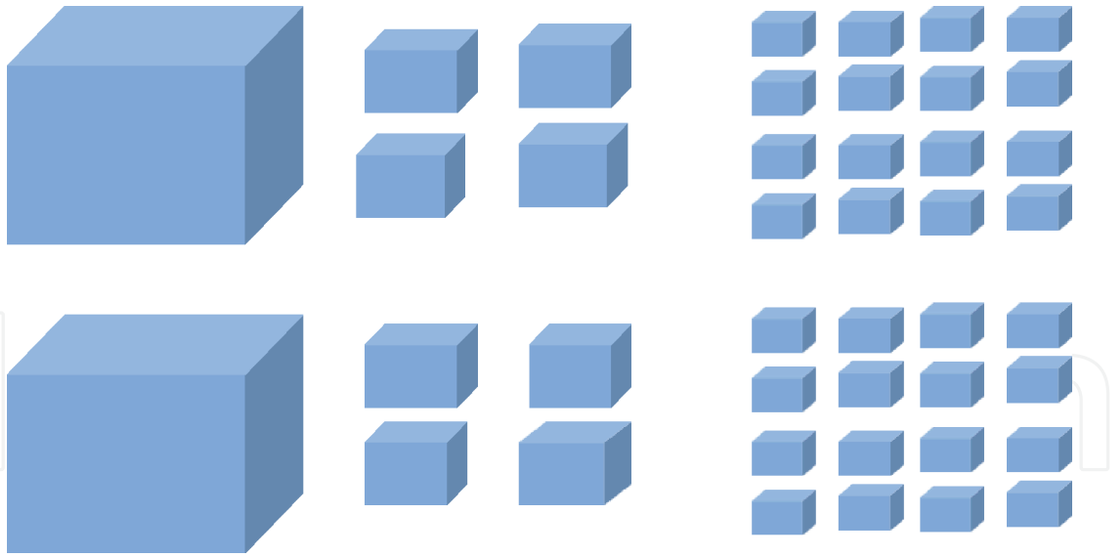

Figure 2.
Schematic drawing showing how surface to volume increases with decreased size.

equal to (*1/d*) and this is the same as that for long cylindrical wires. Thus, the dispersion scales *F* equals to (*1/d*) or (*1/r*) for anything having a very small range of thickness *d*. The dispersion *F* represented the fraction of atoms at the surface and it scales with surface area divided by volume of sphere scales with the square of its radius *r*, but its volume scales with r^3. The total number of atoms *N* in this sphere scales linearly with volume. The corner correction and the edge for large *N* can be negligible, leading to the $N^{-1/3}$ scaling [9]:

$$F = \frac{6n^2 - 12n + 8}{n^3} \tag{1}$$

Or nearly equal to:

$$F \approx \frac{6}{N^{1/3}} \tag{2}$$

3. Prepared nanoparticle

The two basic approaches to creating nanomaterials in a controlled and repeatable manner are the "top-down" and "bottom-up" techniques as shown in **Figure 3**, either for atoms to assemble together (break) or disassemble (dissociate) bulk solids into small pieces or to get on a few atoms from them. This is very important to use at different application fields, for example, in engineering, chemistry, physics, and even medicine. Former approaches play a very important role in modern industry and most likely in nanotechnology as well. In general, nanomaterials can be produced by different methods: mechanical, chemical, hydrothermal, sol-gel, chemical deposition in vacuum, pyrolysis, combustion, chemical co-precipitation, etc. According to these methods, particles are defined by a certain dimensional morphology and distribution can be obtained.

3.1 Top-down

In the physical methods, mechanical methods offer the least expensive ways to produce nanomaterials in bulk (break the particles into nanostructures). But

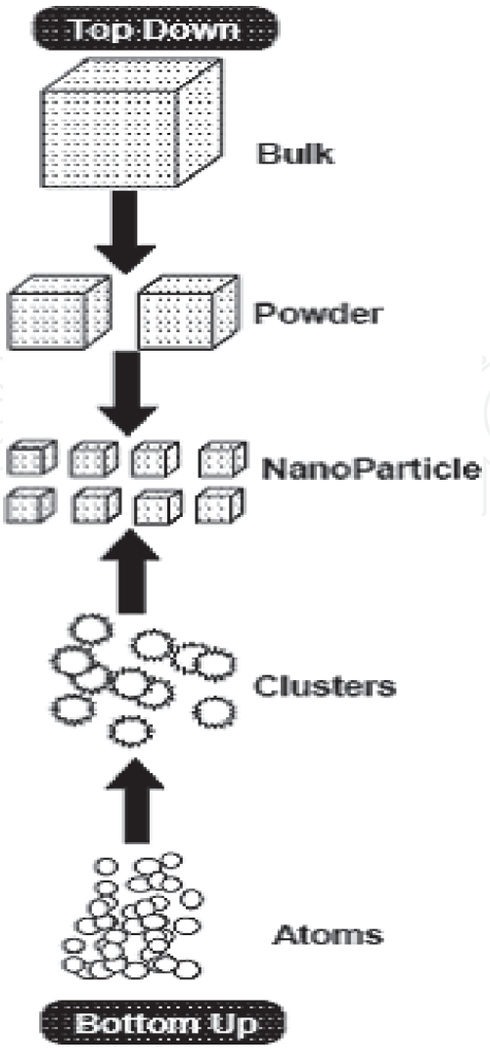

Figure 3.
The scheme to prepare nanomaterial.

chemical fabrication methods are always easy to upscale and many, such as anodizing, are widespread industrial processes [10]. Top-down approach is the process of making nanostructures that start with larger structures and break away to nanosize to form nanomaterials. To obtain nanoscale structures in this method, first, a large object that is (2–3) orders larger in one or two dimensions than the nanoscale desired is fabricated and then nanopatterning techniques are utilized to achieve smaller features. Top-down methods actually was developed firstly by and has been widely used in microelectronics industry. Methods of deposition and nanopatterning of thin films are more advanced, and this approach has been pushed further into the regime of nanofabrication [11]. Also, applying the top-down assembly process of nanocomponents over large areas is difficult and expensive.

3.2 Bottom-up

The building of nanostructures starting with small components such as atoms or molecules is called bottom-up approach. The bottom-up techniques make use of self-processes for ordering of supramolecular or solid-state architectures from the atomic to the mesoscopic scale. The methods of bottom-up include gas-phase and liquid-phase methods. For two methods, fabrication of nanomaterials was controlled when starting from the single atom or molecule. Chemical vapor deposition (CVD) and plasma arcing are called gas-phase methods, whereas liquid-phase (LP)

represented by the most established method is sol-gel synthesis. Also, a new method called molecular self-assembly emerged. The areas of application for nanotechnology have different fields such as photonics, electronics, chemical sensors, biological sensors, and energy storage, and catalysis nanomaterial requires the manipulation into functional materials and devices. Self-assembly is the method important for designing and controlling the bottom-up assembly of the materials in the nanoscale range into structures of sheets, tubes, wires, nanoelectronic devices and drug delivery systems [12].

4. TiO_2/α-Al_2O_3 nanocomposite

In this section, a mechanism for preparing nanomaterials such as TiO_2, Al_2O_3, and TiO_2/α-Al_2O_3 will be explained according to the method of preparation by using sol-gel methods. The sol-gel method was developed in the 1960s mainly due to the need of new synthesis methods in the nuclear industry. The sol-gel process is defined as a gelation means that changes materials by polycondensation reactions from liquid state to gel state. If the dispersion of colloidal particles or polymers is stable in a solvent, it is called a sol, but particles can be amorphous or crystalline in the size of few nanometers. And on the other side, the gel consists of sol particles as continuous network in 3D, enclosed in a liquid phase [13]. There are several methods to prepare TiO_2 nanoparticles using different materials such as tetraisopropyl orthotitanate (TIPT), titanium tetrachloride ($TiCl_4$), ethanol (EtOH), methanol (MeOH), n-hexane, hydroxypropyl cellulose (HPC), 1,4-cyclohexanediol (CHD), triethanolamine (TEA), and TiO_2-P_{25}. In general, it is obtained on gel solution; the gel was filtered and washed subsequently by water and ethanol and then dried at room temperature to get on TiO_2 nanoparticles [14]. Nanocomposites of TiO_2 can be used at different applications in a heterogeneous catalysis, in application of photocatalyst, to produce a hydrogen and electric energy by using a solar cells, gas sensor, white pigment for a paints and cosmetic products, corrosion-protective coating, optical coating, and in electric devices varistors and etc.

On the other hand, Al_2O_3 nanoparticles are prepared by ethanol solution of aluminum nitrate Al $(NO_3)_3.9H_2O$ dissolved in pure water and then added to the solution ethanol from time to time until the color changes. The potential of hydrogen or acidic function (pH) was maintained between 2 and 3 during the synthesis. The white product was evaporated and the result was cooled to room temperature and then finally calcined at high temperature to get on nanoparticles [15]. For TiO_2/α-Al2O_3, nanocomposite was prepared by adding TTIP to isopropyl alcohol under constant stirring and at room temperature (RT = 27°C) and then dispersed of nano-alumina in TTIP solution to form white suspension. Under vigorous stirring, the white gel was formed. Then, this gel was heated at high temperature in a Teflon-lined autoclave. Finally, the collection powder of nanocomposite was yields by during the gel [16].

5. Properties of nanomaterials

The nature of all materials in bulk has different properties, which are depended on their structural properties (metals, semiconductors, and insulators), such as electrical, optical, and mechanical properties. Nanoparticles have properties that are different from small molecules; in this case, their chemistry and synthesis can be considered like complex mixtures.

The ability of the molecules to contact of nanoparticles on the surface and exchange with other molecules leads to the indicates that will be careful consideration of the chemistry of nanoparticles and how it relates to their fate in surface waters and sediments, this is a key to predicting their final fate [17]. When one of the three spatial dimensions is of a size comparable or smaller to wave length of de Broglie (λ_B) of the charge carrier of electrons and holes or the wavelength of light, the crystalline materials are destroyed by the periodic boundary conditions or change the atomic density on the surface of amorphous materials. Because of this property, a lot of the physical properties of nanomaterials are quite different from bulk materials, yielding a wide variety of new applications [18].

5.1 Mechanical properties

The mechanical properties of materials depend essentially on the nature of bonding that holds their constituent atoms and their microstructures in a variety of length scales. Mechanical deformation can be either elastic (reversible) or plastic (irreversible) [19]. Elastic materials respond to stress fields via strain fields; liquids respond via viscous strain rates; and complex fluids are often describable via frequency-dependent viscoelastic responses. Many properties of crystals, magnets, liquid crystals, superconductors, superfluids, and field theories of the early universe can be described by focusing on long length scales, assuming that the materials are close in equilibrium. On the other hand, plastic materials can be defined as irreversible deformation, and different mechanisms may be responsible: dislocation motion, vacancy motion, twinning, phase transformation, or viscous flow of amorphous materials [20]. The proportional relation between the stress and the elastic strain is given by Hooke's law, which can be written as follows:

$$\sigma \propto \varepsilon \tag{3}$$

$$\sigma = Y\varepsilon \tag{4}$$

where σ is the stress, ε is the strain, and Y is the modulus of elasticity or Young's modulus.

The size of grain for polycrystalline materials, depending on strength and hardness, is well established as Hall-Petch relationship, which indicates that the yield stress and hardness are inverse to the square root of the grain size. This strengthening at reduced grain sizes is attributed to the pile-up of dislocations at grain boundaries. However, when it comes to Nanocrystalline regime, the conventional Frank-Read dislocation sources ceases to control the deformation due to the stress to bow out a dislocation approaches the theoretical shear strength [21]. The relation between yield stress and grain size is described mathematically by:

$$\sigma_y = \sigma_o + \frac{k_y}{\sqrt{d}} \tag{5}$$

where Eq. (5) is called Hall-Petch relationship, and k_y is the strengthening coefficient, σ_o is a materials constant for the starting stress for dislocation movement, d is the grain diameter, and σ_y is the yield stress.

5.2 Electrical properties

The electrical conductivity, DC, for nanoparticle materials (or metals) is affected by the microstructure. The value of conductivity (DC) appears by grain

boundary contribution, which depends on DC bias voltages but grain contribution does not depend on it. The grain boundaries in nanocrystalline materials often have significant influence on the flow of electronic current. The microstructure at scale of length is smaller or similar to the mean free path of conduction electrons, this produced a grain boundaries a main source of eight conduction electrons scattering [22]. The measurement of the electrical properties is also important because the connectivity of a composite system from SEM and TEM micrographs cannot be deduced alone. The DC electrical conductivity (σ_{dc}) of the crystal was calculated using the relation:

$$\sigma_{dc} = t/RA \tag{6}$$

where R is the measured resistance, t is the thickness of the sample, and A is the area of the face in contact with the electrode. The temperature variation of conductivity is given by using Stuke's Equation [23]:

$$\sigma_{dc} = \sigma_o \exp\left[-E/kT\right] \tag{7}$$

where σ_o is a constant depending on material, E is the activation energy, T is the absolute temperature, and k is the Boltzmann's constant.

On the other hand, the AC conductivity of the media (composites) (σ_m) is the sum of the real and imaginary conductivities, which are given by:

$$\sigma_m = \sigma_{mr} + i\sigma_{mi} \tag{8}$$

The conductivity of the more conducting component is given by:

$$\sigma_c = \sigma_{cr} + i\sigma_{ci} \tag{9}$$

For ideal conductivity where ($\sigma_{cr} >> \sigma_{ci}$) Eq. (9) read as:

$$\sigma_c = \sigma_{cr} \tag{10}$$

For the insulating component, the conductivity is given by:

$$\sigma_i = \sigma_{ir} + i\sigma_{ii} \tag{11}$$

where $\sigma_{ii} = \omega\varepsilon_0\varepsilon_{ir}$.
Eq. (11) can be approximated when ($\sigma_r << i\sigma_{ii}$) as:

$$\sigma_i = i\omega\varepsilon_0\varepsilon_{ir} \tag{12}$$

In practice, σ_{ir} incorporates both, a usually very small, DC conductivity and the dielectric polarization loss term ($\omega\varepsilon_0\varepsilon_{ii}$). The expressions for σ_c and σ_i can be dispersive and/or temperature-dependent. [24].

5.3 Optical properties

When light incidents from one medium into another, several things are happened see **Figure 4**. Some of the light radiation may be transmitted through the medium, some will be absorbed, and some will be reflected at the interface between the two media. The total intensity (I_o) of the incident light striking a surface is equal to the sum of the absorbed (I_A), reflected (I_{oR}), and transmitted (I_T) intensities, that is

$$I_o = I_T + I_R + I_A \tag{13}$$

where T, A, R are transmissivity, absorptivity, and reflectivity, respectively. And

$$T = {}^{I_T}\!/_{I_o} \tag{14}$$

$$A = {}^{I_A}\!/_{I_o} \tag{15}$$

$$R = {}^{I_R}\!/_{I_o} \tag{16}$$

So Eq. (13) becomes:

$$1 = T + R + A \tag{17}$$

One can estimate the absorption coefficient (α) of thin films after the correction of reflectivity as:

$$\alpha = \frac{2.303}{t} A \tag{18}$$

where t is the thickness of the material.

It is very important to study α in order to define types of the electron transition, such as allowed direct, forbidden direct, allowed indirect, and forbidden indirect. The transition is allowed if $\alpha > 10^4$, when $\alpha < 10^4$ the transition is forbidden direct. From the absorption coefficient data, one can calculate the extinction coefficient (K) as [25]:

$$\lambda = \frac{4\pi}{\alpha} K \tag{19}$$

where λ is the wavelength of the incident light.

An alternative way to boost optical absorption is to use nanostructure-based devices to attain multiple band gaps based on the size of the quantum dots or quantum wells (based on quantum mechanics, the size of the dot or well determines the band gap of the material). For silicon as an example, the nanostructure results in direct band gap material, and the optical absorption is enhanced due to an increase of oscillator strength. The value of the oscillator strength was one of silicon nanostructures and the reduced mass is taken as a half mass of electron rest mass. For a cluster of 18 atoms, the band gap energy is taken as (1.82) eV with radius 1 nm. The absorption coefficient for nanostructure is given as [26]:

$$\alpha_d \cong \frac{5.4 \times 10^5}{n(\lambda)} \left[\frac{1.24}{\lambda} - 1.82\right]^{\frac{1}{2}} \left(cm^{-1}\right) \tag{20}$$

where λ, is measured in μm and $n(\lambda)$ is the refractive index given by Herzberger's formula.

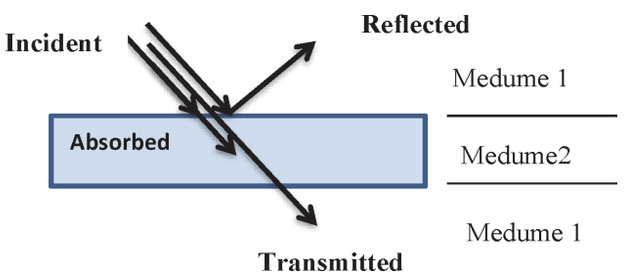

Figure 4.
Diagram of the interaction of light with matter.

$$n(\lambda) = 3.2346 + \frac{0.3698}{\lambda^2 - 0.028} \tag{21}$$

6. Characterization methods

In recent years, it was found that the nanomaterials are very important, and they keep growing in the field of nanoscience and nanotechnology. The researchers used various nanomaterials in the synthesis and application process, due to their potential in the application of science and industry. For example, biocomposite nanomaterials are applied directly and used to replace natural materials to work or to be in contact with the living systems. There are several methods to determine the type of material in the range of nanoscale [27]. Nanoparticle formation is analyzed by using UV-visible spectroscopy and characterization of nanoparticles by SEM, TEM, XRD, FTIR, and EXD. Each method is based on measurements that differ from the other and can be carefully compared. Many of these methods focus on examining particle size at the nanoscale to determine the average particle size of a sample. The role properties of nanoparticles depend on the size and shape, and few particle size distributions of commercial products are narrow in range. In this chapter, the focus is on diagnosing nanocomposites using known techniques that are as follows:

6.1 Transmission electron microscopy (TEM)

A microscopy technique in which a beam of electrons is transmitted through an ultra-thin specimen, and the interaction with the specimen as it passes through it is called transmission electron microscopy (TEM). When the electron beams are transmitted through the specimen as shown in **Figure 5**, the strong interaction between the specimen (atoms) and the electrons duo helps form an image. The image detected by a sensor such as a charge-coupled device (CCD) camera or focused on the device to be an image, such as a fluorescent screen, on a layer of photographic film [28]. Specimens are needed to be very thin, usually below 100 nm in thickness, to achieve good signal-to-noise ratio and sufficient contrast in transmission. Transmission electron microscopy techniques provide two-dimensional images of nanoparticles; these images can be used to produce number-based size distributions, but nanoparticles have all three external dimensions on the nanoscale, and performance properties often depend on their physical-chemical characteristics, that is, size, shape, surface structure, and texture. [29]. The perfect sample of transmission electron microscopy for nanoparticle size analysis is one with a large number of individual particles in nanoscale within the desired TEM micrograph field of view, but without excessive agglomeration or bunching of nanoparticles. There are two factors that may have an effect on the TEM grid of the nanoparticle number density: the derivatization efficiency process and the concentration of nanoparticles in solution [30]. Typically, the calculated sizes are expressed as a sphere diameter that the particle has the same projected area as the projected image. Particle size analysis was done using manual or automatic techniques. The first analysis used to get a mean result by obtain a linear dimensional measure of the particle divided by the number of particles, it's usually based on the marking device. To get a clear image, the preparation was elaborated and is slow with few particles being examined [31]. The resolution of image is related to the amplitude and phase alterations in the electron beams that are determined by the contrast transfer function (CTF) as:

$$CTF = A(q)e^{iX(q)} \tag{22}$$

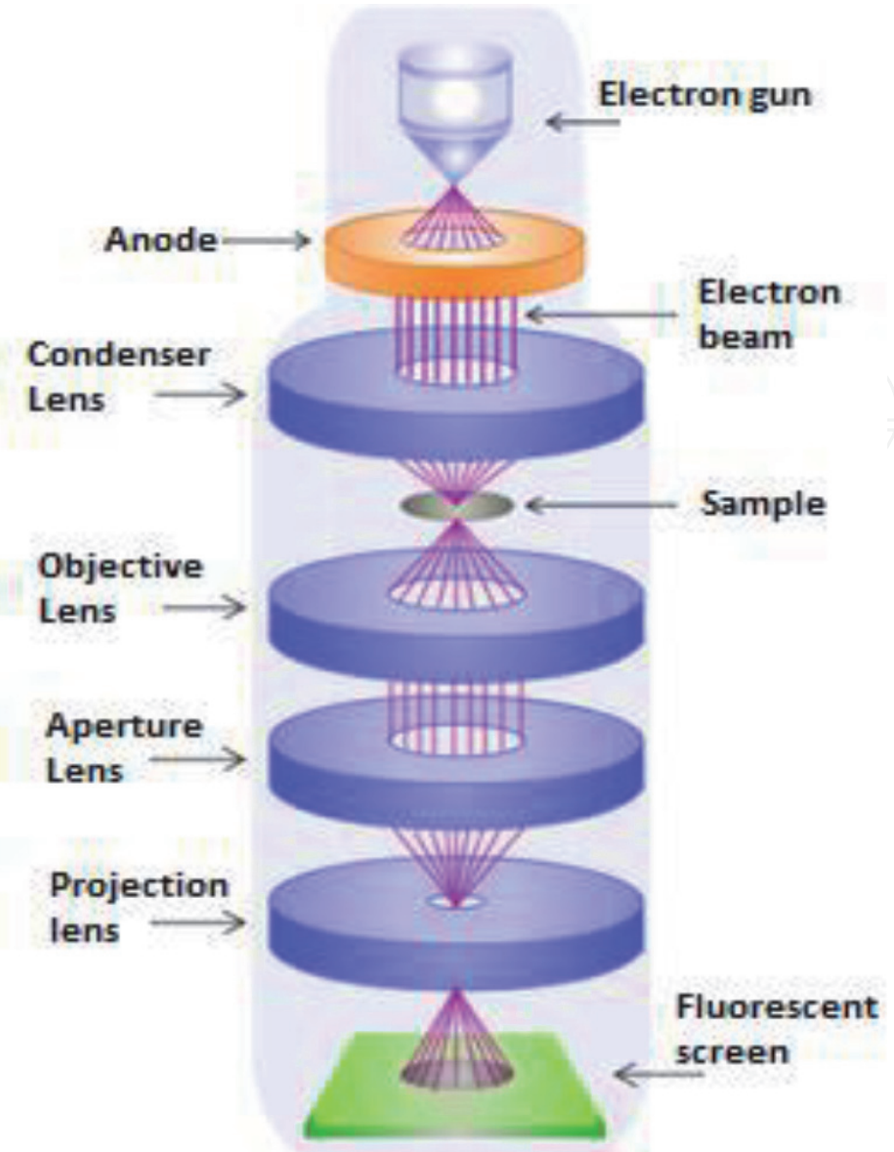

Figure 5.
Schematic form of transmission electron microscopy.

where A (q) describes the diffraction diagram truncation by the aperture of the objective lens and $e^{iX(q)}$ is the phase function, which is described as the distortion of the output wave by the objective lens.

6.2 Scanning electron microscopy (SEM)

The scanning electron microscopy (SEM) is an electron microscope that creates images for the sample surface by scanning it with a high energy stream of electrons [32]. The scheme of SEM is illustrated in **Figure 6**.

The surface morphology of the materials was investigated using scanning electron microscopy (SEM) technique. This technique is different from transmission electron microscopy at site of specimen and intensity of electron beams. For TEM, the electron beam penetrates the sample, but for SEM, the electron beam is incident on the surface of the sample. SEM provides information about surface morphology and composition of materials. There are several advantages for SEM technique in morphological and sizing analysis, but the information is limited for distribution size and true average population. The investigate of solution of nanoparticles with

SEM needed to drying to get on a powder from it before mounted on a sample holder and coating a conductive metal on the surface of sample, such as gold, using a sputter coater. The surface sample is scanned when a high energy stream of electrons is incident on it [33]. The high-resolution magnified images produced when the revealing details about less than 1–5 nm in size and for narrow electron beam yields a characteristic three-dimensional for understanding the surface sample structure.

6.3 X-ray diffraction (XRD)

X-ray diffraction (XRD) is defined as the nondestructive technique that provides detailed information about the crystallographic structure, chemical composition, and physical properties of materials. When the beam of monochromatic incident on the target materials the interaction between them is happened and the scattering of those X-rays from atoms within the target material can be illustrated in **Figure** 7. Bragg's law was used to explain the interference pattern of X-rays scattered by crystals structure the diffraction of

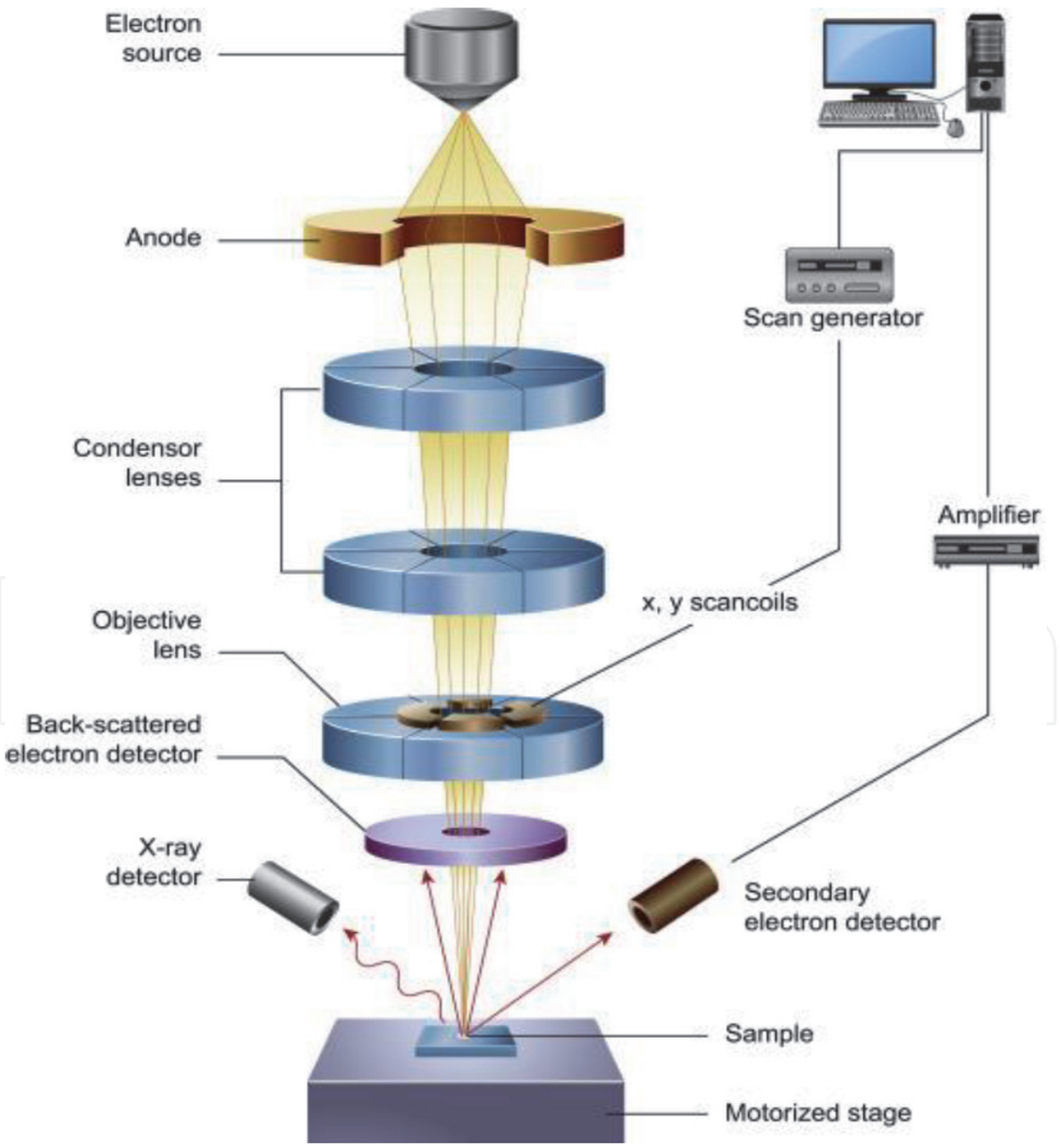

Figure 6.
Schematic form of SEM.

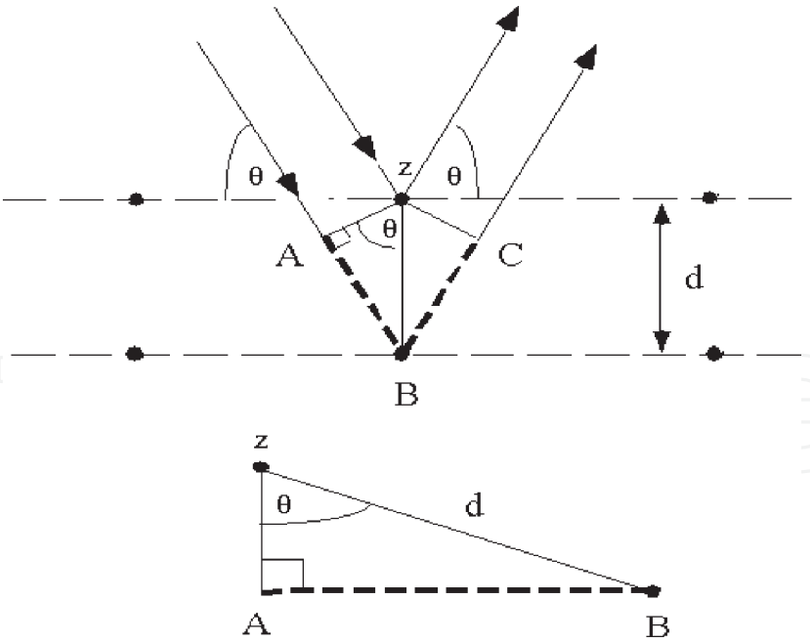

Figure 7.
Schematic diagram of the interaction of the X-ray with mater.

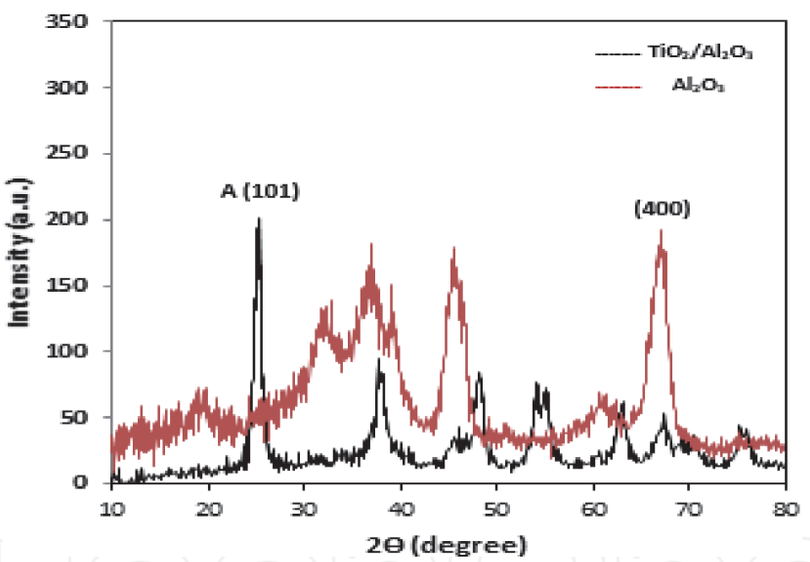

Figure 8.
XRD pattern of Al_2O_3 and TiO_2/Al_2O_3 nanocomposite.

X-rays described by [34]:

$$n\lambda = 2d\,sin\theta \tag{23}$$

where n is an integer, λ is the wavelength of the X-rays, d is the interplanar spacing generating the diffraction, and θ is the diffraction angle.

X-Ray diffraction (XRD) can be considered as a good technique for analyzing the nanostructures, because the width and shape of reflections yield information about the substructure of the materials (sizes of microcrystallites, microdistortions of a lattice, dislocation structures, etc.). There are several approaches to analyze the X-ray diffraction line profiles, with the Scherrer, Williamson-Hall, and Warren-Averbach methods being most widely applied [35].

The Scherrer formula was used by most material scientists as the simplest method of particle size determination. The formula proposed by P. Scherrer in 1918 describes the broadening of diffraction reflection peaks as a function of the average particle size D [16]:

$$\beta = k\frac{\lambda}{D\,cos\varphi} \tag{24}$$

where k is equal to:

$$k = 2\sqrt{(ln\,2)/\pi} \approx 0.94 \tag{25}$$

and k is the shape factor, λ is the incident x-ray wavelength (0.15040 nm for CuK), β is full width at half maximum (FWHM), and φ is diffraction angle at maximum intensity peak.

XRD pattern of Al_2O_3 and TiO_2/Al_2O_3 nanocomposite is shown in **Figure 8**. The diffraction Al_2O_3 peaks can be well indexed to pure α-Al_2O_3 (JCPDS Card no. 880826). The appearance of diffraction peaks in TiO_2/Al_2O_3 XRD pattern corresponding to (101) and other planes is in good agreement with the standard XRD peaks of Anatase TiO_2 (JCPDS Card No. 040477). The average crystal sizes of nanocomposite materials for TiO_2/α-Al_2O_3 (21.4 nm) are larger than Al_2O_3 (8.1 nm), which leads to get a good mix of NPS.

7. Nanotechnology applications in the environment

Nanoparticles that are produced deliberately using specific processes are called engineered or manufactured nanoparticles, for example, fullerenes and CNTs. With regard to environmental issues, the system of one dimensional (1D), thin films, or surfaces of two dimensional (2D), this can be used in applications of electronics, chemistry, and engineering as thin films at the range of sizes (1–100 nm) or monolayer in the field of solar cells or catalysis. These thin films are inserted in different technological applications, including development of a new generation of environmental sensing systems, chemical and biological sensors, fiber-optic systems, and magneto-optic and optical device.

The sun sends an infinite light free from environmental pollution and noise is a renewable source of energy. The energy drawn from the sun can easily compensate for nonrenewable sources of energy such as fossil fuels and petroleum deposits on the earth. The solar cells have passed through a large number of improvement steps from one generation to another, because of their importance for the generation of alternative energy [36].

7.1 Solar cell

Photovoltaic (PV) is related to the devices such as solar cell that directly converts sunlight into electricity. The solar cell is the elementary building block of the photovoltaic technology. Silicon is one of the most common semiconductor materials that is used to make solar cells. One of the most common properties of semiconductors that makes them most useful is that their conductivity may easily be modified by introducing impurities into their crystal lattice. There are several types of solar cells, and they are either cut from a single crystal rod or from a block composed of many crystals and are correspondingly called monocrystalline or

multicrystalline silicon solar cells and nanocrystal-based solar cells [37]. Most solar cells are fundamentally large areas of p-n junctions. When light shines on them, they can generate current and voltage, the photons produce electron-hole (e–h) pairs, and the dipole electric field provides for a separation of these charges. The reason this can happen is because of the "built-in" electric field at the junction of the p-type and n-type material [36]. The junction between them creates a charge separation region with a strong dipole electric field.

The current-voltage (I-V) characteristics of photovoltaic cell are illustrated in **Figure 9**, which operates under normal conditions. The power curve is obtained when a solar cell produced power and then the current and voltage $(I \times V)$ are the products. Most solar cells behave as a diode in the dark, admitting a much larger current under forward bias (V > 0) than under reverse bias (V < 0). For an ideal diode, the dark current density varies as:

$$J_{dark} = J_o\left(e^{qV/K_BT} - 1\right) \tag{26}$$

where J_o is a constant. Thus, the net current flowing in a circuit powered by a solar cell is:

$$J(V) = J_{sc} - J_{dark} \tag{27}$$

$$J(V) = J_{sc} - J_o\left(e^{qV/K_BT} - 1\right) \tag{28}$$

where I_{sc} is the current of short-circuited and V_{oc} is the voltage of open circuit.

The maximum power is obtained when ($V=V_m$ and $I=I_m$) and the fill factor (FF) is defined by the ratio [38]:

$$FF = \frac{V_m I_m}{V_{sc} I_{sc}} \tag{29}$$

where V_m, I_m is the maximum voltage and current, respectively.

Quantum efficiency (QE) is the ratio of the number of charge carriers collected by the solar cell to the number of photons of a given energy incident on the PV device [39]:

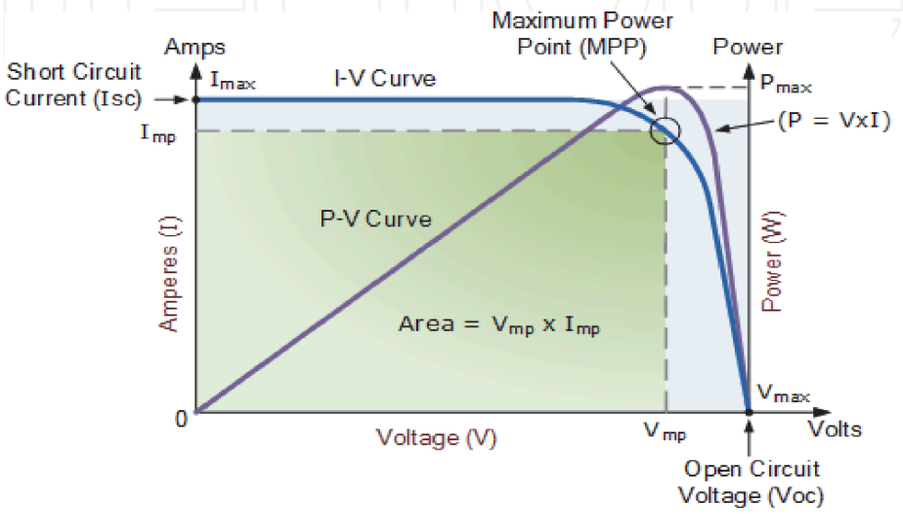

Figure 9.
(I-V) Characteristics of a typical PV cell.

$$QE = \frac{P_{out}}{P_{in}} = \frac{P_m}{P_s} \tag{30}$$

Where is the maximum power and $P_m = V_m I_m$,Ps is incident light power.

7.2 Nanocoatings

Coating is defined as a coherent layer formed from a single or multiple applications of coating materials to a substrate. According to the existing standard, coating material is a material in liquid, paste, or powder form that, when applied, forms a protective and decorative coating. Some nanomaterials are suitable for use in transparent coating systems. In addition, the transparency of these nanomaterials such as TiO_2 nanoparticle in visible light makes it possible to create novel additives introducing new properties to otherwise nontransparent coatings. The choice of the manufacturing process depends on the specific application and the specific application requirements of the coating. The sol-gel process may offer several advantages to manufacturers: the manufacturing process is shorter, runs at lower temperatures, and consumes less energy.

The properties of Titanium dioxide (such as high photocatalytic efficiency, chemical stability, low toxicity, and low cost) made it most thoroughly used from other materials. Also, self-cleaning paints with other metal oxides like ZnO have been reported [40]. The self-cleaning researchers are mostly about air pollution and environmental contamination in buildings especially on indoor and outdoor building surfaces. The wide range of applications of self-cleaning was necessary to focus on various materials for different purposes [41]. Although the properties of surfaces of self-cleaning are complex, however, it is related to several of their surface characteristics. At the beginning, the surfaces are superhydrophilic and water droplets are spread across the surface making it easier to wash off solid material. Then any organic material coating on solid particles will react with these surfaces by photocatalytic reactions to allow them to fall or wash off more readily. The surfaces of TiO_2 have very high electroconductivity. A surface with high electroconductivity provides antistatic properties repelling charged particles and preventing their accumulation on the surface. In addition, the waterborne paint is prepared by the mill base for the pigment dispersion in water, auxiliary solvents, etc. Then the mill base is blended with the binder (polymer latex) and the paint is obtained [40].

7.3 Sonocatalyst

The chemical effects of ultrasound are not derived from a direct coupling of the acoustic field with chemical species on a molecular level. Instead, sonochemistry and sonoluminescence derive principally from acoustic cavitation [42]. In the past decade, the expansion of the sonoelectrochemistry has become increasingly important. The variety of induced effects on electrochemistry processes by ultrasound waves can be attributed to the generation, growth, and collapse of microbubbles in the electrolyte. There is a growing interest of the application of the sonoelectrochemistry in environmental remediation and in the preparation of nanopowders [43]. Ultrasounds have a wide range of uses in the development of applications of nanoparticle solutions for different chemical compounds. The effect of ultrasonic energy breaks the chemical bonds of compounds [44]. The ultrasonic catalytic degradation method has been widely used in wastewater treatment because of its many excellent properties; these are simple equipment, have high efficiency and stable operation, are safe, and cause no secondary pollution. Improvement of ultrasonic catalysis process is known as a sonocatalyst [45]. It has received great

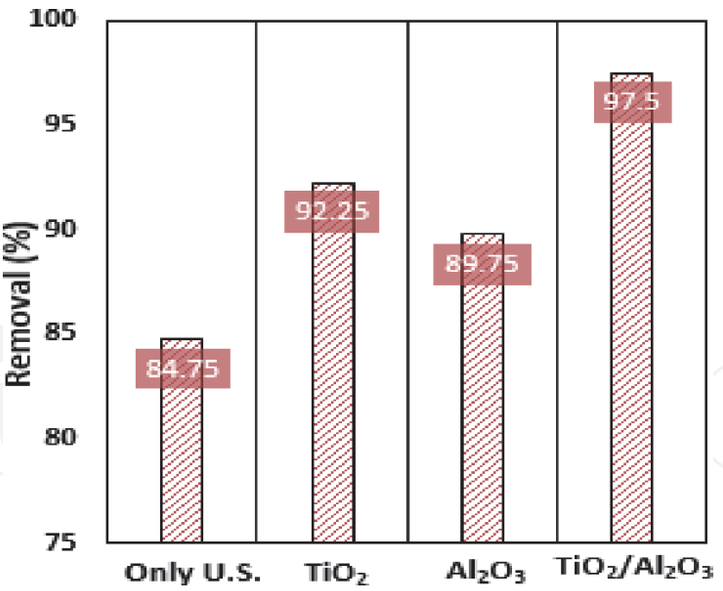

Figure 10.
The sonocatalysis effect on MB decolorization.

attention as a useful and promising method for mineralizing organic pollutants, for example, synthetic dyes in aqueous media. In this process, water molecules are used to produce hydroxyl radicals, which are very reactive and non-selective oxidants and are capable of decolorizing and mineralizing dyes to CO_2 and H_2O. The oxidation processes of a metal oxide semiconductor are advanced through ultrasonic treatment on surface [46]. The presence of semiconductor particles (i.e., TiO_2, ZnO) enhanced the process of breaking up the microbubbles created by the ultrasound irradiation into smaller bubbles, and these proses will be increasing the quantity of high of high temperatures and pressures, this leads to produce additionally amount of hydroxyl radicals which will attack the pollutant and resulting in degradation of the pollutant. Sonochemical decolorization of dyes under initial concentrations using ultrasonic processor represented by the effect of nanocomposite of Al_2O_3, TiO_2, and TiO_2/Al_2O_3 on the decolorization of methylene blue dye was clear as shown in **Figure 10**. The increase in the decolorization of dye in the presence of nanoparticles due to these nanoparticles act as catalysts that increase the number of nucleation of the cavity and improve the rate of dissociation of water into highly reactive hydroxyl radicals (·OH). TiO_2/Al_2O_3 nanocomposites show highly removal of Methylene blue dye than other Sonocatalysts due to highly dissociation rates H_2O molecules that yields more free radical generated, thereby increasing the rate of degradation of the organic compounds [16].

8. Conclusion

Nanomaterials can be used in different applications such as in medicine, electronic device, sunscreens, military applications, photovoltaic cells, paints, catalysts, etc. Some of these do not have an effect on the environment, while others have an effect on it. In this chapter, the focus of our attention was on the applications that do not affect the environment and improve it, so the important property that surface to volume ratio of nanomaterials increases with decreases particle size. To do that, the processes of preparing nanoparticles are physical and chemical methods, and the sol-gel process is basic to prepare nanomaterials in chemical methods such as TiO_2, Al_2O_3, and TiO_2/α-Al_2O_3 because it can be used at low

temperature and short time. These can be used in solar cells to produce clean energy, nanotechnologies in coatings, and sonochemical decolorization of dyes.

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